Associated Higgs Boson Production with Heavy Quarks

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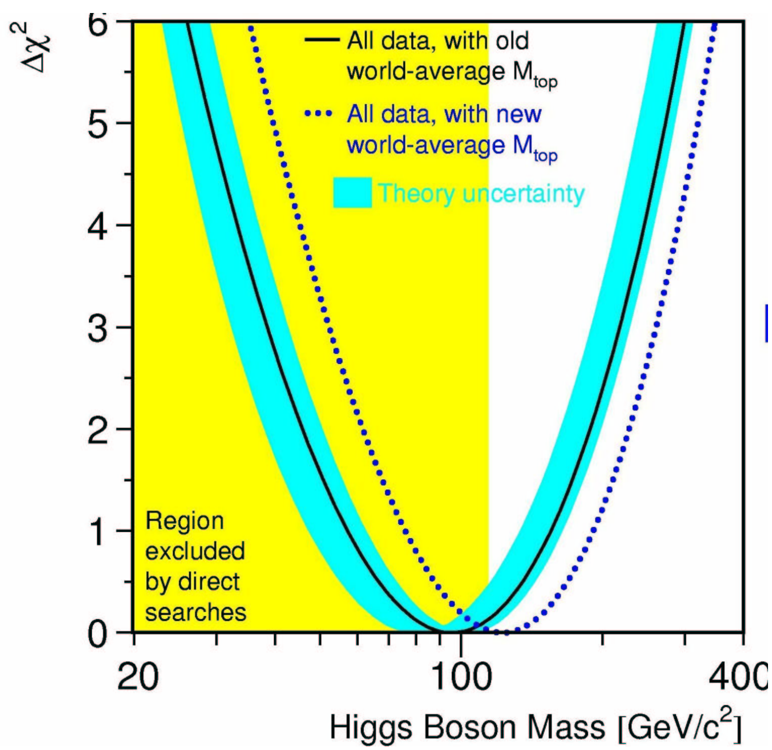
Victoria, July, 2004

- Motivation (discovery, precision studies)
- $pp \rightarrow b\bar{b}H, t\bar{t}H$ (LHC)
- $p\bar{p} \rightarrow b\bar{b}H, t\bar{t}H$ (Tevatron, Run II)
  - With emphasis on:
- Theoretical predictions
- Relevance to Higgs Boson studies
  - With L. Riena, C. Jackson, L. Orr, D. Wackeroth

Strong case for a light scalar Higgs boson, both SM and MSSM

NEW

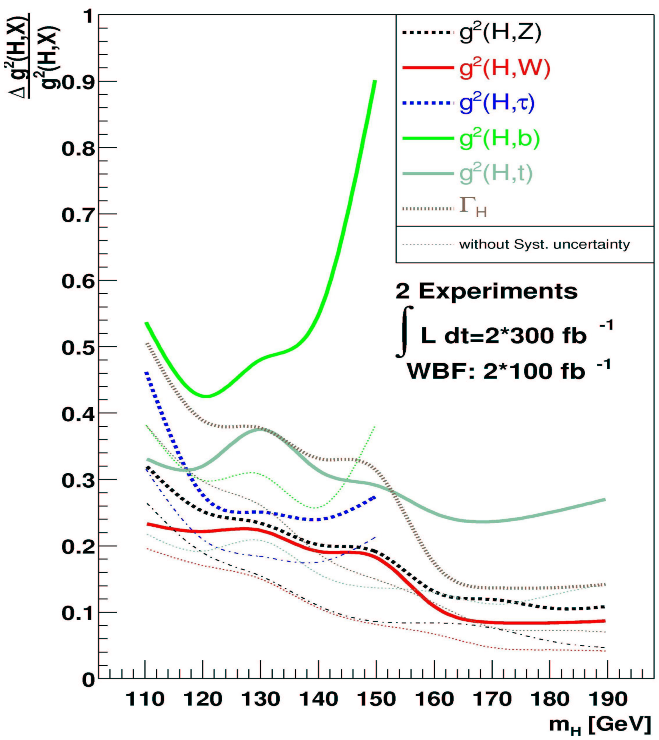


- Old:
  - M_t=174±5.1 GeV
  - M_H=96^{+60}_{-38} GeV
  - M_H< 219 (95% cl)
- New:
  - M_t=178±4.3 GeV
  - M_H=117^{+67}_{-45} GeV
  - M_H < 251 (95% cl)

Best fit not in region excluded from direct searches

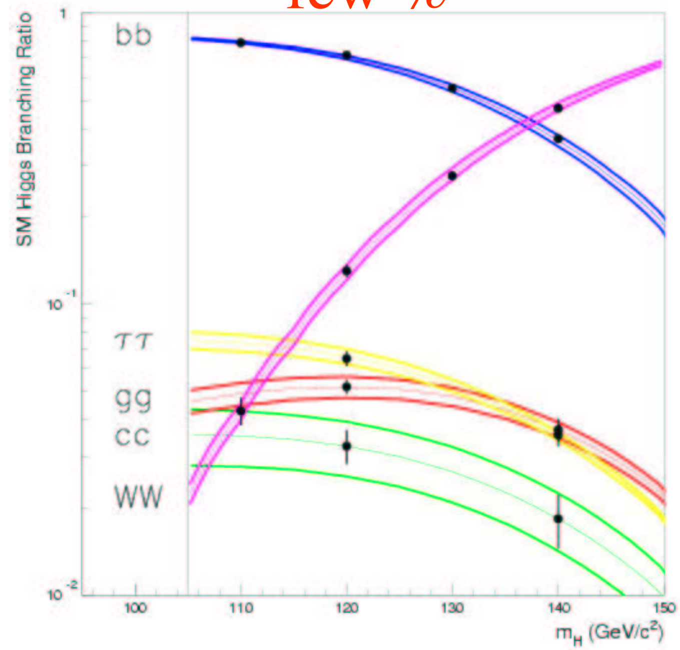
Once we find the Higgs, we need to measure its couplings

Coupling constants measured quite precisely at LHC



Duhrssen, Heinemeyer, Logan, Rainwater, Weiglein, Zeppenfeld hep-ph/0406323

LC measures couplings to a few %



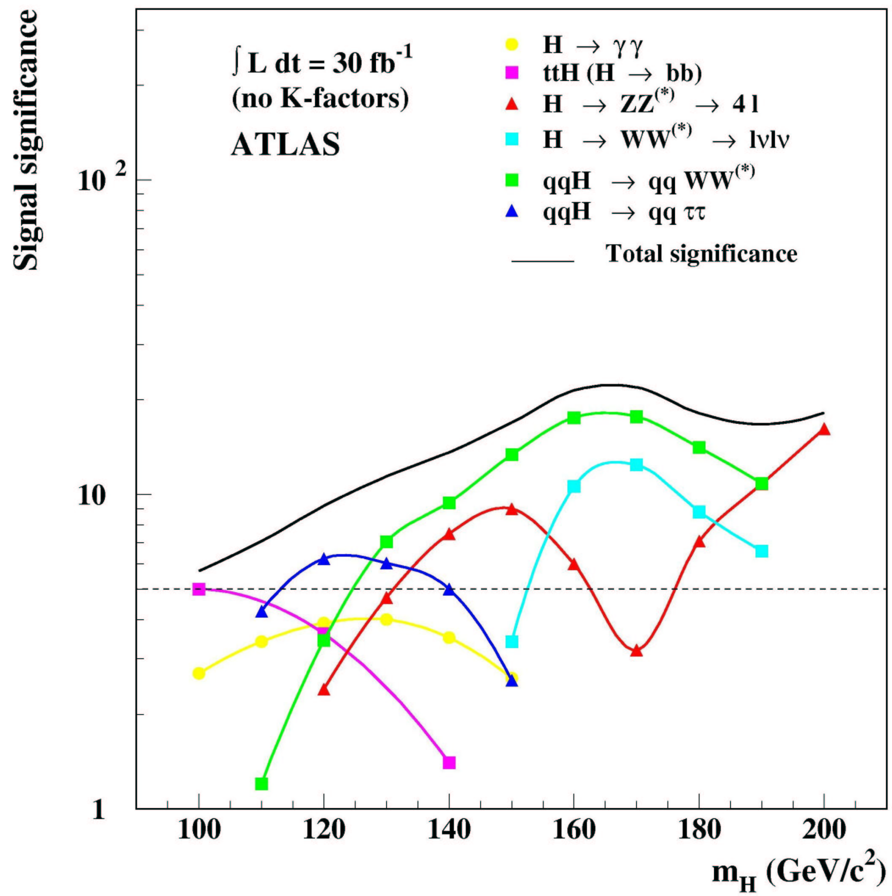
e^+e^- LC at $\sqrt{s}$=350 GeV

L=500 fb^{-1}, M_H=120 GeV

Battaglia & Desch, hep-ph/0101165

Linear Collider is the place!

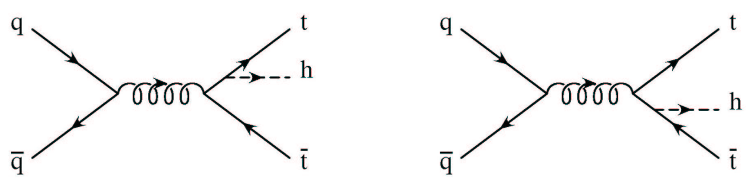
ttH is important for LHC Discovery

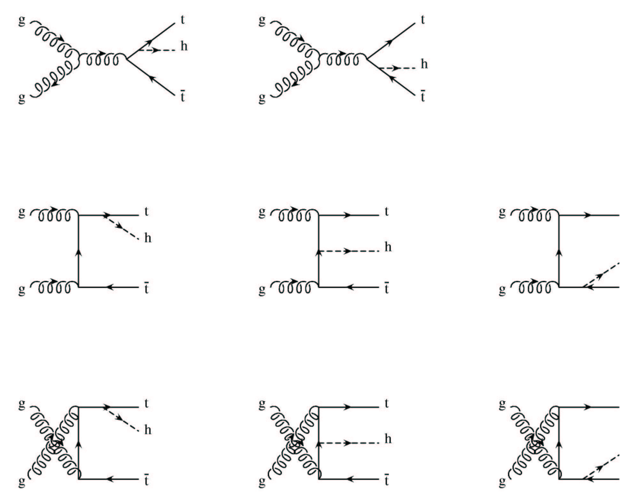


General Framework

$pp \to t\bar{t}H$ important for discovery at the LHC

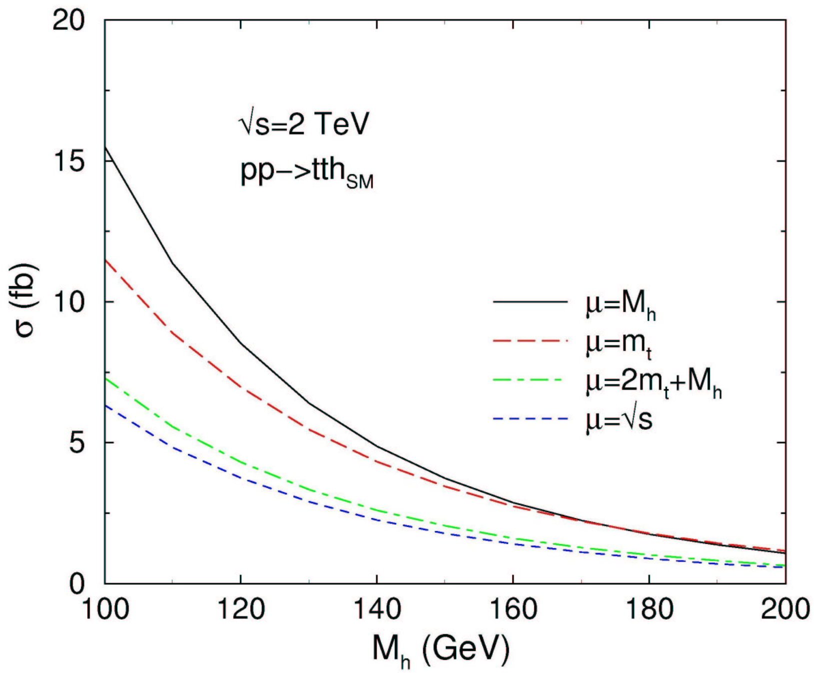
Only $t\bar{t}H$ production can measure directly the top Yukawa Coupling (Y_t): $\boxed{\sigma \approx Y_t^2}$

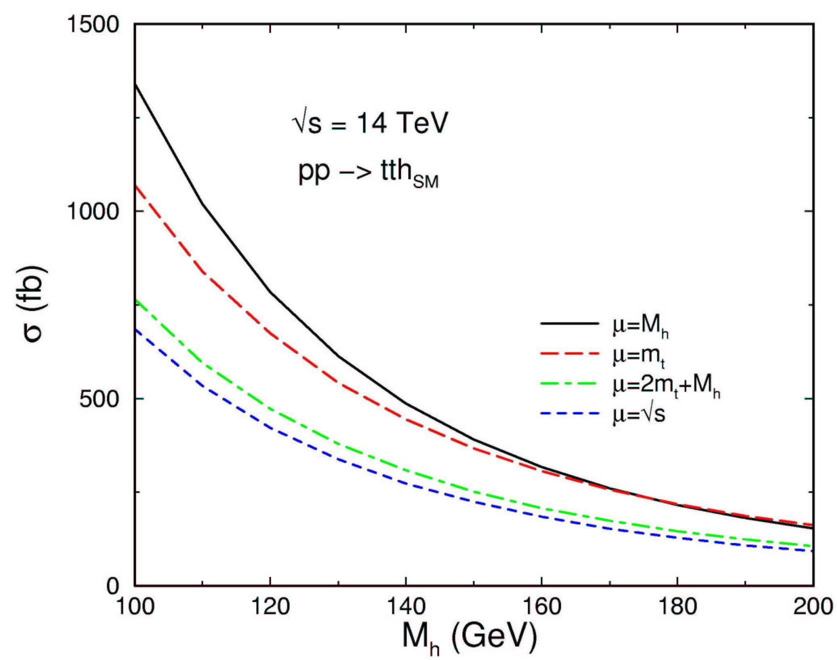




$pp, p\bar{p} \to t\bar{t}H$
Need for NLO calculation

Tree level cross sections have very strong μ dependence

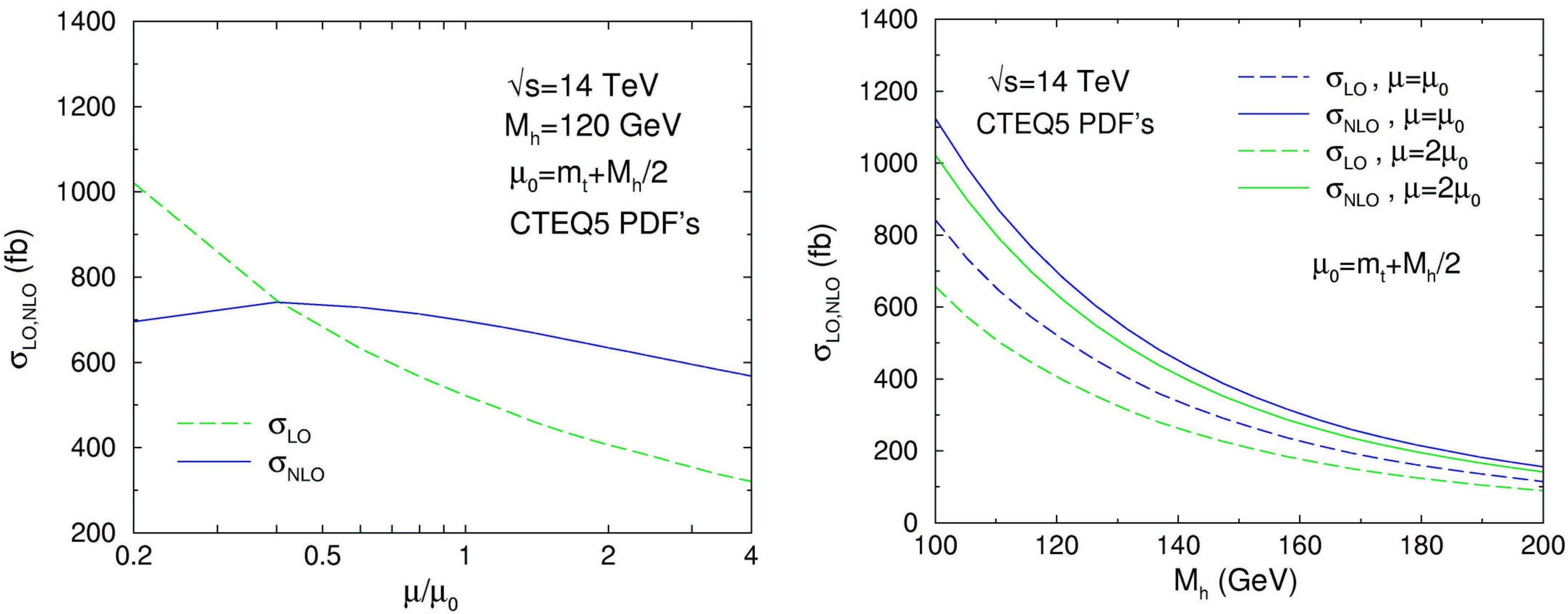




NLO O(α_s^3) corrections by 2 groups: Beenakker, Dittmaier, Kramer, Plumper, Spira; Dawson, Reina, Orr, Wackeroth

LHC, NLO cross section:

$$pp \to t\bar{t}H$$

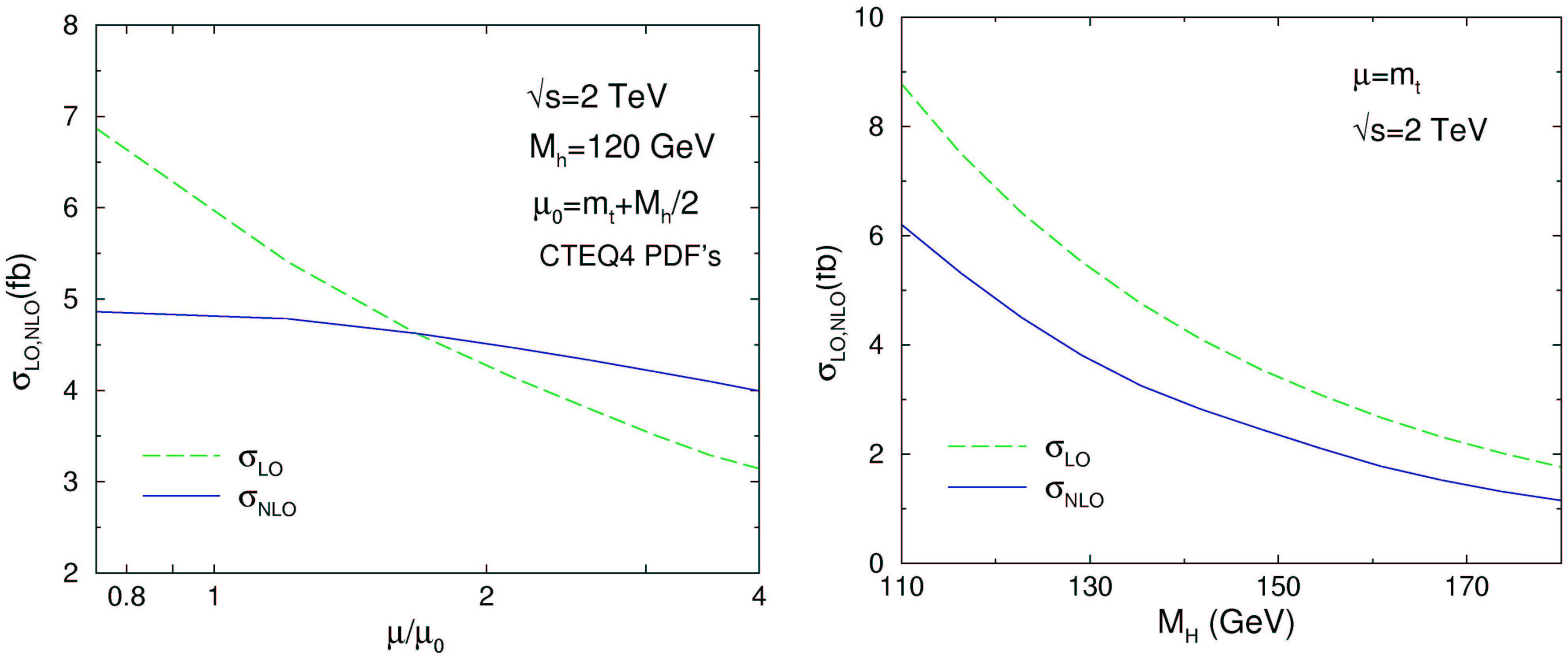


Theoretical uncertainty reduced to about 15%

Dawson, Jackson, Reina, Orr ,Wackeroth, hep-ph/0305087;
Beenacker et al, hep-ph/0211352, hep-ph/0107081

Tevatron, NLO cross section

$$p\bar{p} \rightarrow t\bar{t}H$$



Note reduced μ dependence of NLO result

Rate too small to be observed at Tevatron

Reina, Dawson, Wackeroth, hep-ph/0109066; Reina, Dawson, hep-ph/0107101; Beenacker et al, hep-ph/0211352, hep-ph/0107081

What about bbH?

- In SM, bbH couplings suppressed by

  $(m_b/v)^2 \approx .0004$

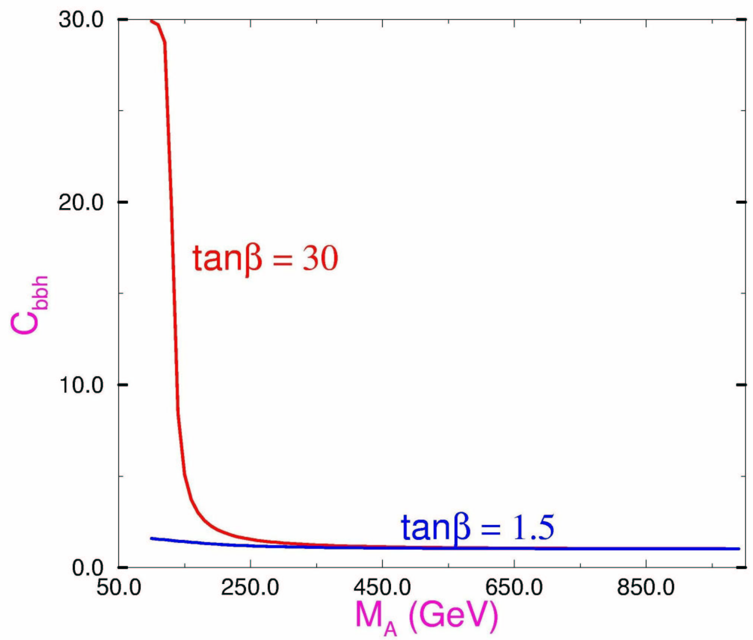
- SUSY models have more Higgs bosons

  h_0, H_0, A_0, $H^{\pm}$

- At tree level, couplings depend only on

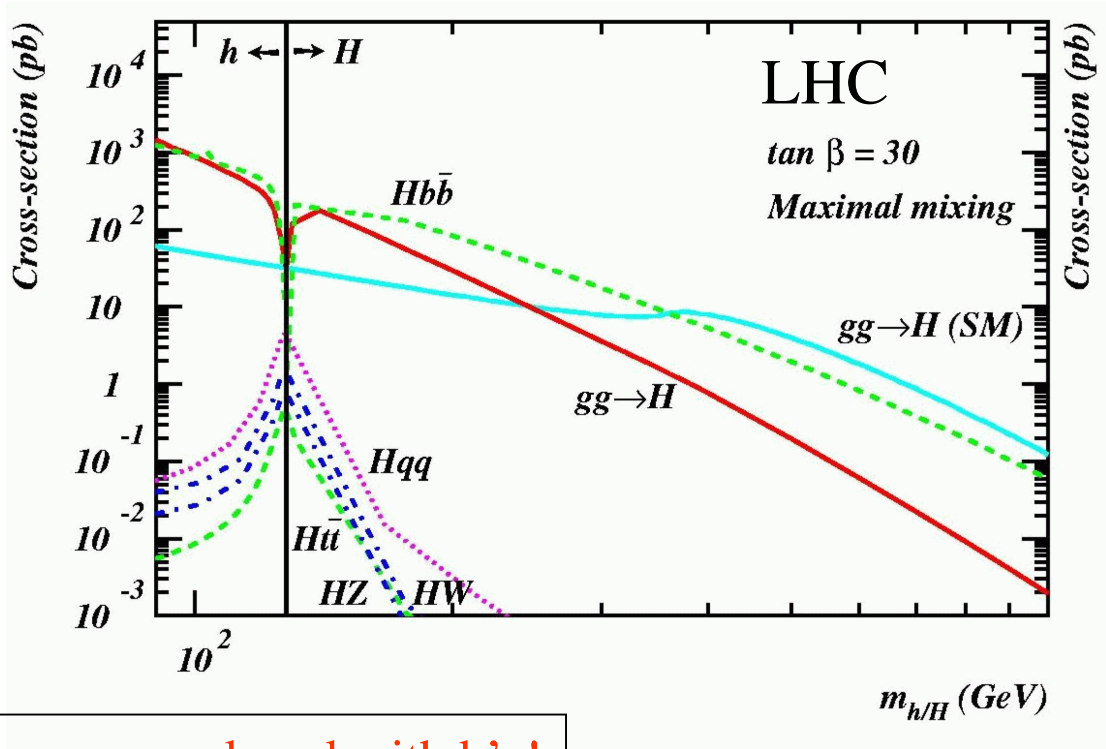
  $\tan\beta$, M_A

Can be huge enhancement!



Production of SUSY Higgs Bosons

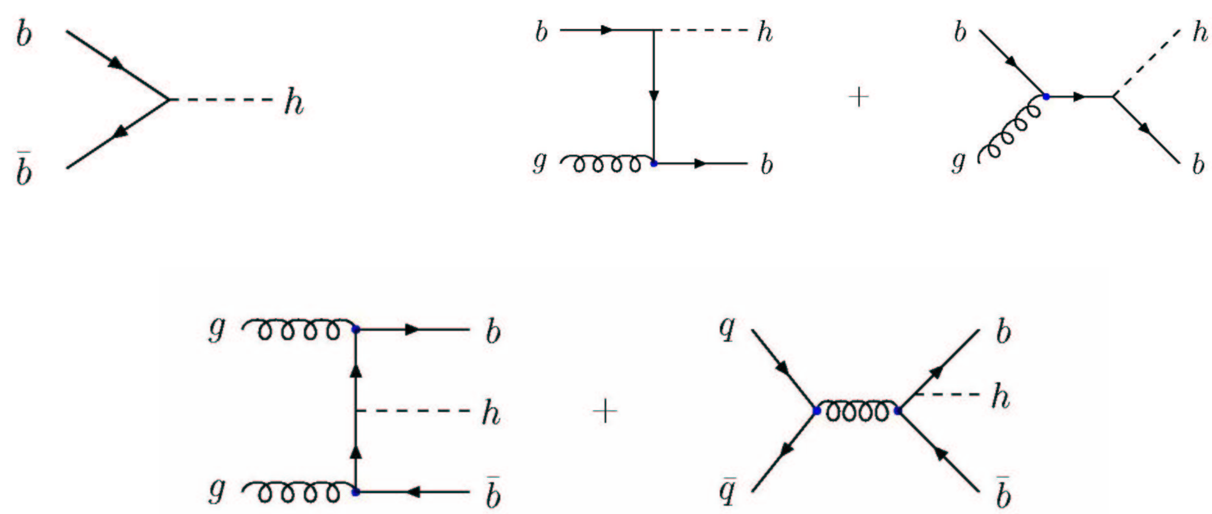
- For large tan β, dominant production mechanism is with b's
- bbh can be10x's SM Higgs rate in SUSY for large tan β



SUSY Higgs are produced with b's!

Spira

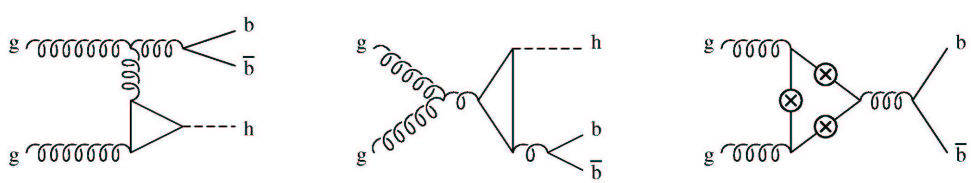
What is the dominant process?



Answer depends on whether you tag outgoing b’s

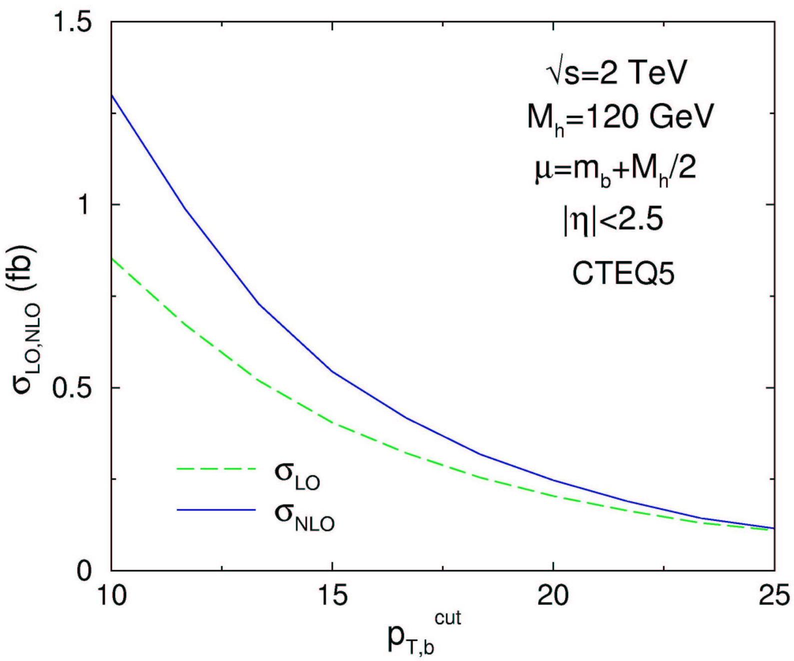
$p\bar{p} \rightarrow b\bar{b}H$ at NLO

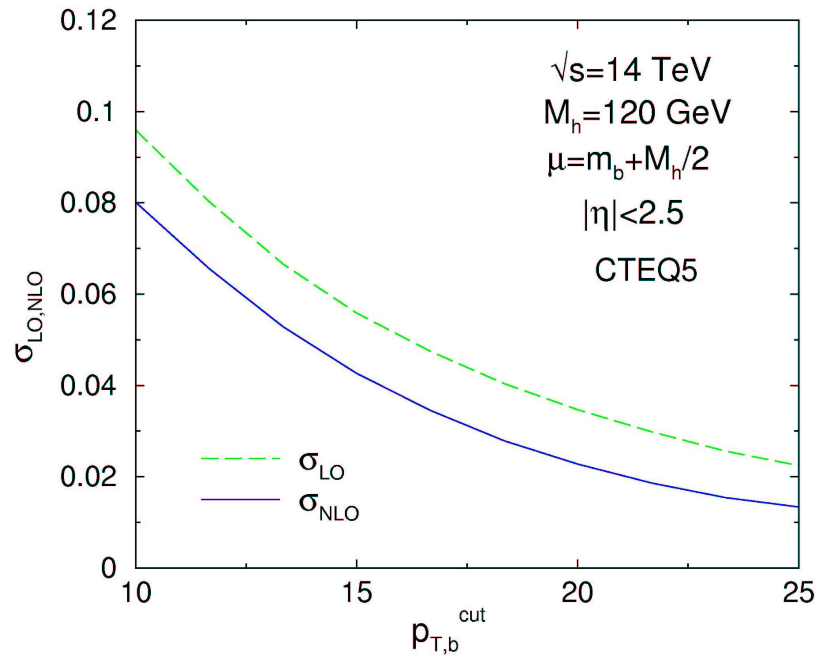
- Almost identical calculation to tth calculation
  - Dominant contribution at both Tevatron and LHC is gg initial state
  - Virtual + real corrections computed numerically using phase space slicing
  - b quark mass included everywhere
  - Differences: closed loops with top quarks, numerical problems from large $\log(m_b/M_H)$



$pp, p\bar{p} \rightarrow b\bar{b}H$

Strong dependence on p_t^b cuts:

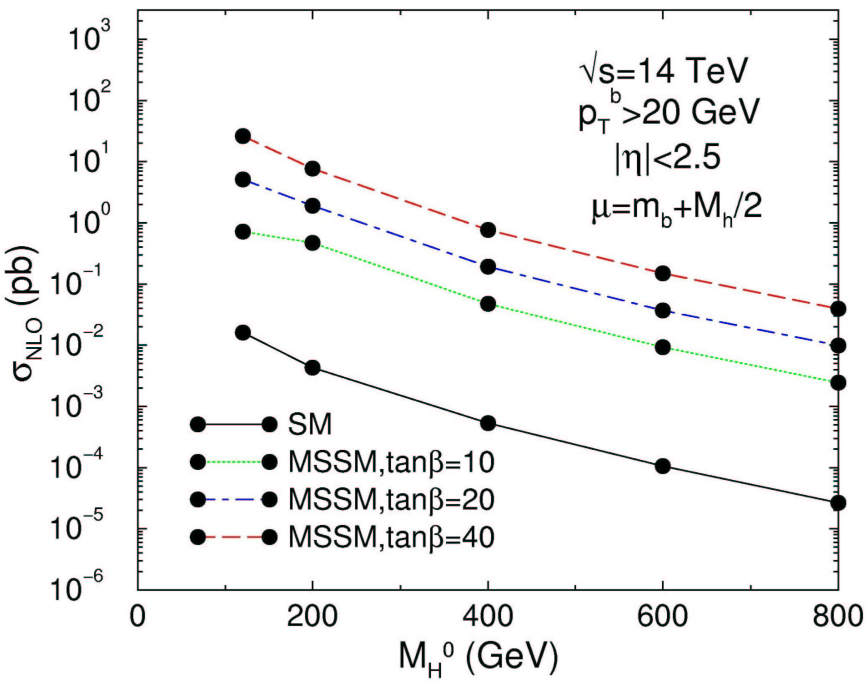




Dawson, Jackson, Reina, Wackeroth, hep-ph/-311067; Dittmaier, Kramer, Spira, hep-ph/0309204

$pp, p\bar{p} \to b\bar{b}H$
Enhancement in MSSM

Note log scale!

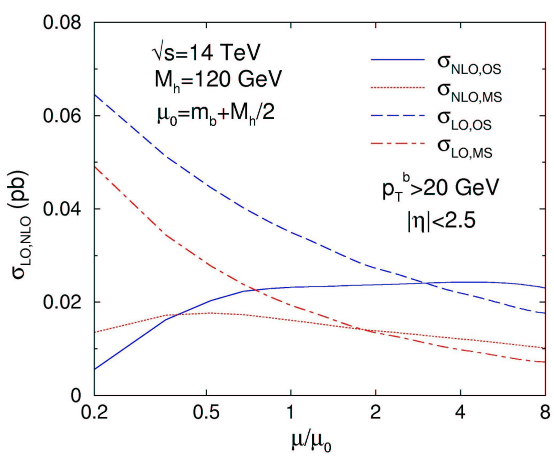


Can observe heavy MSSM scalar Higgs boson

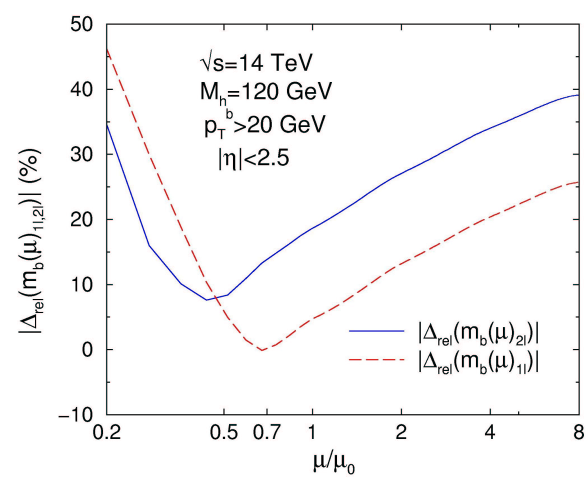
Large Residual Scheme Dependence

- Not obvious what "best" scheme is

$$pp \rightarrow b\bar{b}H$$



- Large remaining scale/scheme dependence between OS and $\overline{MS}$ at NLO



- Effect ≈ 10-20%

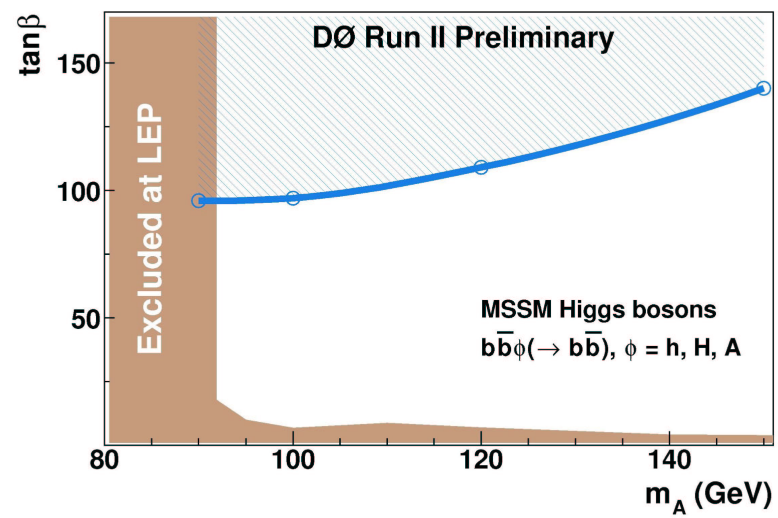
Inclusive and semi-inclusive bbH production

- Two approaches:
  - Fixed flavor approach
    - Fixed order matrix element calculation based on the processes $gg \to bbH$, $qq \to bbH$
  - Variable flavor number scheme:
    - Use b quark PDF to sum to all orders large logarithms $\alpha_s \log(M_H^2/m_b^2)$ which arise due to gluon splitting $g \to bb$ to collinear b's

bH production at NLO

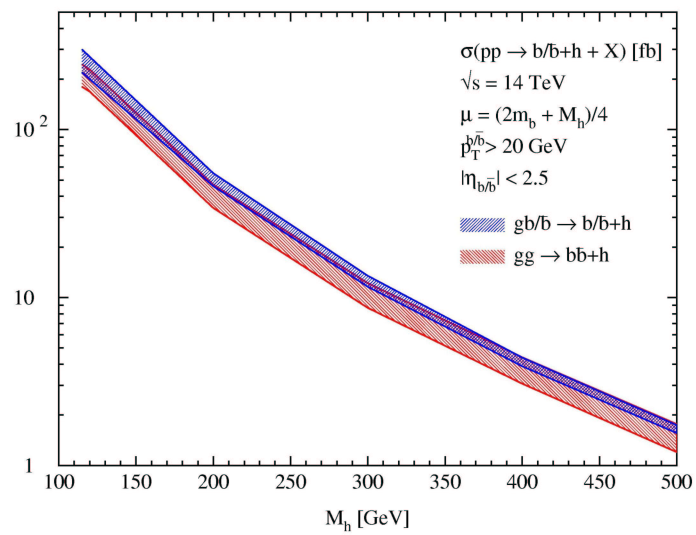
- Larger rate than 2-b tag process
- Extra b tag and Higgs transverse momentum improve detection efficiency from 0-b tag process ($bb \to H$)
- Variable flavor number scheme, dominant process is $bg \to bH$
- Fixed flavor number scheme, dominant process is $gg \to bbH$

D0 search: tag 3 b's

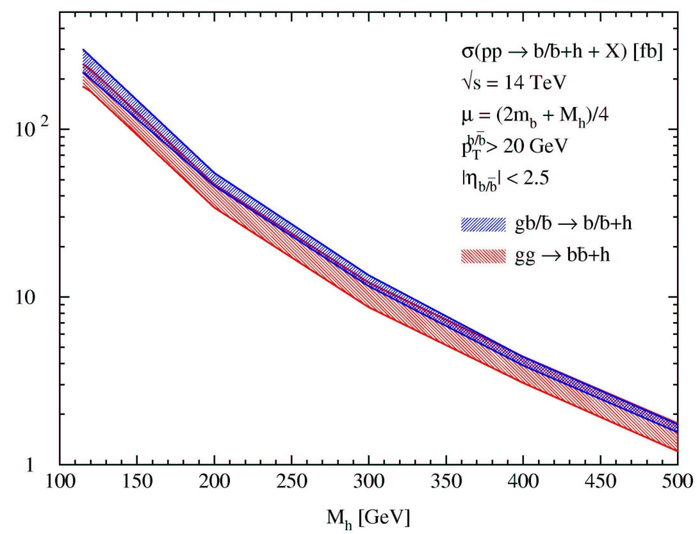


Exclusive cross section for $pp \rightarrow b\bar{b}H$: 1 b tag

- Compare *variable flavor number scheme* with *fixed flavor number scheme* for PDFs

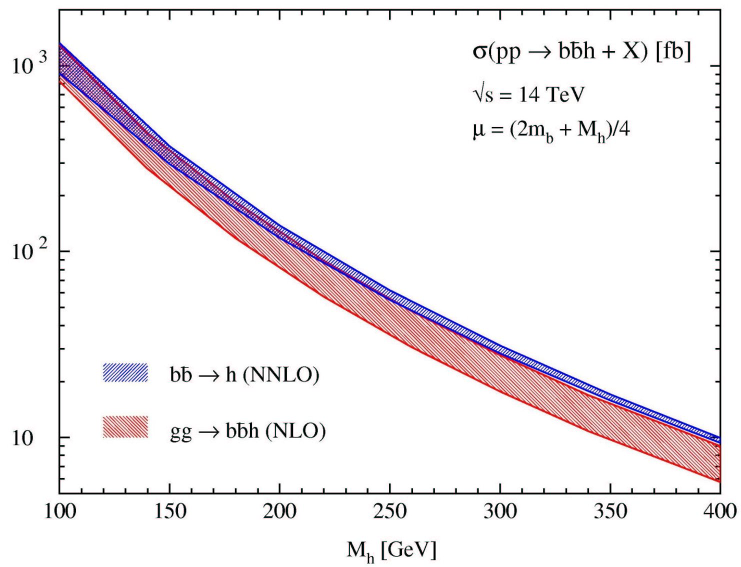


No closed top loop in gb curves

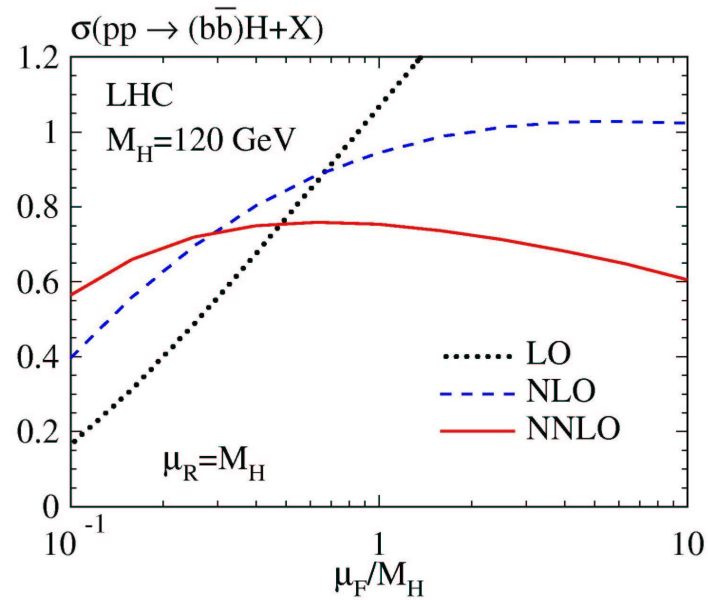


Campbell et al, hep-ph/0405302

Inclusive Cross Section for bb→H: 0 b tags



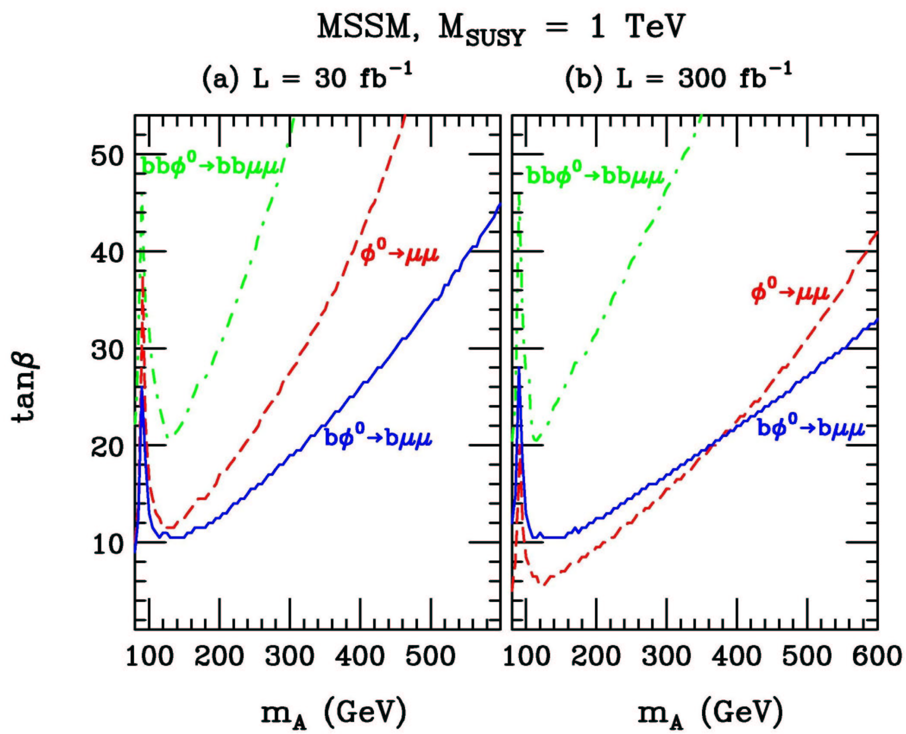
Campbell et al, hep-ph/0405302



Harlander & Kilgore, hep-ph/0304035

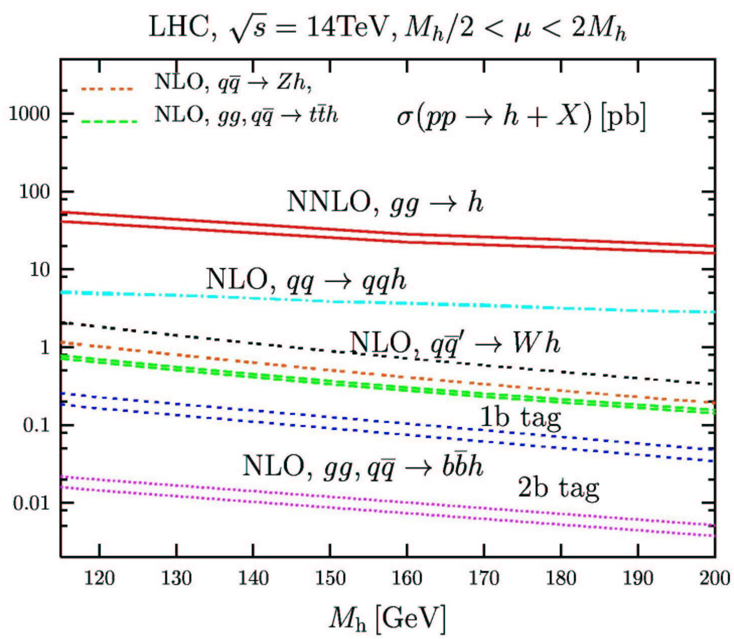
bb→H in MSSM

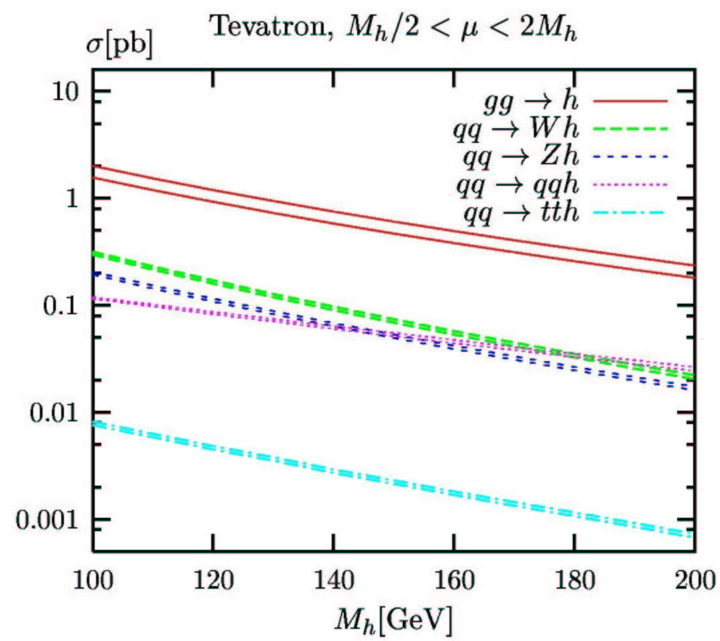
5σ discovery region



Dawson, Dicus, Kao, Malhotra, hep-ph/0402172

State of the art predictions for Higgs production



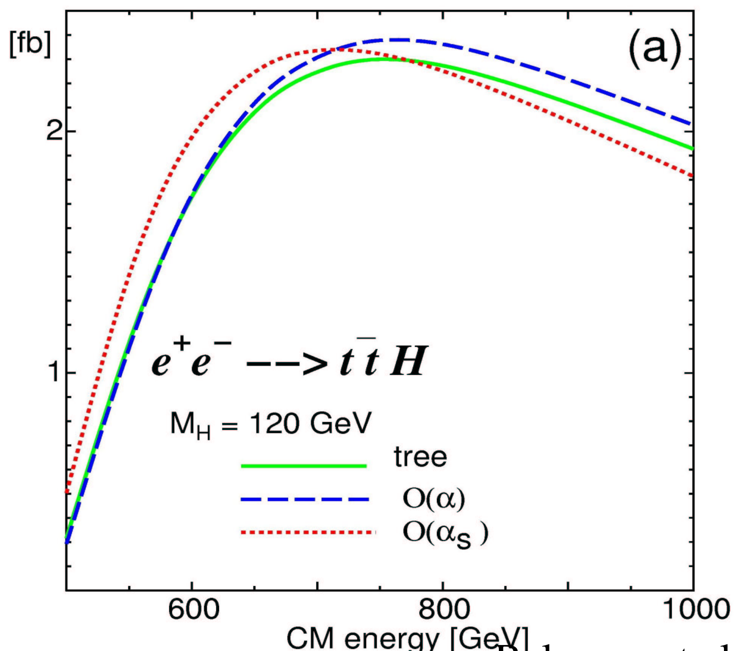


Bands represent factorization/renormalization scale uncertainty

Dawson, Jackson, Reina, Wackeroth

QCD &EW Corrections to $e^+e^- \to tth$ Production

Cancellation of QCD & EW corrections at high √s



Belanger et al, hep-ph/0301040

Denner, Dittmaier, Roth, Weber, hep-ph/0309274

Conclusion

- ttH, bbH interesting production modes at Tevatron and LHC
- Top Yukawa coupling: the LHC can play a crucial role and complement a $\sqrt{s}$=500 GeV LC
- Enhanced bbh: possible signal of New Physics at the Tevatron and LHC
- Crucial to have NLO QCD corrections: theoretical uncertainty greatly reduced